Hybrid III-V Photonic Crystal Waveguide Laser on Silicon Wire

Y. Halioua[1,2], A. Bazin[1], T. Karle[1], P. Monnier[1], I. Sagnes[1], G. Roelkens[2], R. Raj[1] and F. Raineri[1,3]
[1]Laboratoire de Photonique et de Nanostructures, (CNRS-UPR20), 91460 Marcoussis, France
[2]Photonics Research Group, IMEC/Ghent University, St-Pietersnieuwstraat 41, 9000 Ghent, Belgium
[3]Université Paris Diderot, Paris, France

Abstract: We report laser emission from InP-based wire cavities bonded to silicon on insulator wafers. Both, Cavities bonded to unpatterned wafers and bonded to wafers with singlemode waveguides are studied.

OCIS codes: (130.5296) Photonic crystal waveguides, (140.5960) Semiconductor lasers

1. Introduction

Small volume cavities based on a periodic line of holes in a waveguide (wire cavities) are being extensively studied both theoretically and experimentally for the high Q/V factor they offer. Even though work on these cavities began some time ago [1] it is only recently that impressive Q factors have been demonstrated which brings many of the predicted applications closer to reality. These high Q factors have even been obtained not only on suspended membranes but also on low index substrates such as SiO_2 which makes them suitable for use in devices. So far a lot of attention has been devoted to passive 1-D cavity and nanocavity beams[2]. However, incorporating an active element has not been explored yet though it is an exciting possibility as the strong light confinement promises ultra-small lasers with low laser thresholds. Making them CMOS compatible would open up myriads of applications. For this, the most efficient way would be to combine III-V active elements and low-loss passive silicon photonic circuitry drawing benefit from the technological advancement in both material systems. This, however, is not straight forward as it involves hybrid structures. In this communication, we report results on III-V semiconductor wire cavity photonic crystal (PhC) lasers which are bonded on top of an unpatterned SOI as well as on SOI waveguides. We obtained low threshold lasing and the emitted light is coupled out evanescently to the Si wire, channelled out, coupled to a fibre and detected. It should be emphasised that the footprint of the laser is 5µm^2!

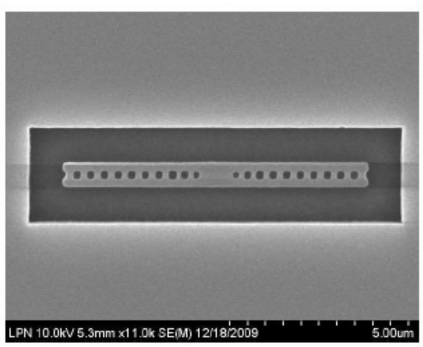

Figure 1: SEM picture of a wire cavity bonded to unpatterned SOI wafer

2. Wire cavity bonded to unpatterned SOI wafer

We firstly explored structures made in an InP-based membrane containing 4 InGaAs/InGaAsP quantum wells emitting at 1,55µm bonded to an unpatterned SOI wafer (see Fig. 1). Here, the Si and the InP layers are separated by a 1µm-thick BCB polymer (n=1.53) in order to prevent losses of the cavity towards the substrate. Using 3D FDTD we simulated the cavities. The length of the cavity was varied between 265 nm and 1250 nm in steps of 25 nm to obtain resonances ranging from 1400nm to 1580 nm. Eight-hole mirror configuration was chosen as a trade-off between reflectivity and losses due to the hole roughness. For all the different sets of the cavity lengths it is seen that the Q peaks to a value of about $7x10^4$ (see circular dots on Fig. 2a).

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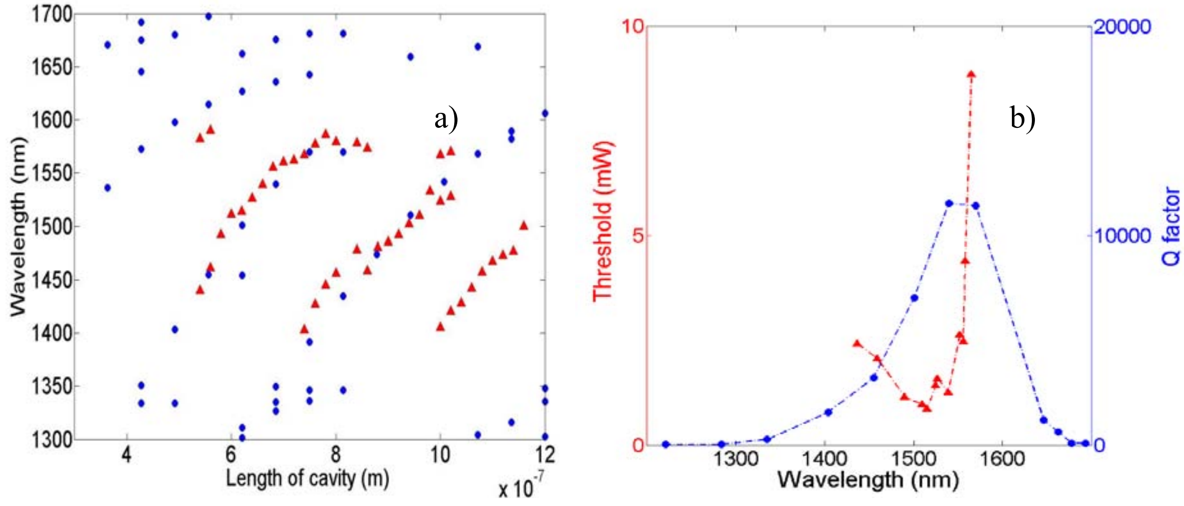

Figure 2: a) Resonant wavelength vs length of cavity.. b) Q factor and laser threshold vs cavity length. Blue round dots are 3D FDTD calculations results and triangular red dots experimenal ones in both figures,

We measured at room temperature the light emitted under optical pumping. The samples are surface pumped using 50X IR long working distance objective. The laser source used for pumping is a diode laser that we modulate so that it produces 10ns pulses at 200kHz repetition rate, the characteristics being chosen so as to minimise heating. The wavelength of the diode laser is at 808nm. This NIR pump is absorbed by each of the semiconductor materials, InP, InGaAs QWs and their InGaAsP barriers. The light emission around 1.5µm from the III-V PhC is collected by the very same objective, is separated from the pump by a dichroic mirror and is analysed using a spectrometer equipped with a cooled InGaAs photodiode array. Experimentally, laser emission was demonstrated for various cavity lengths and consequently various wavelengths. The wavelength of emission matches very well with the simulation results (Fig. 2a). Threshold of the lasers are around 1.5 mW external power. Taking into account the length of the cavity and gain at different wavelengths, we compared thresholds for various cavities. We observe that the thresholds match beautifully with the curve of Q extracted from modelling (Fig 2b).

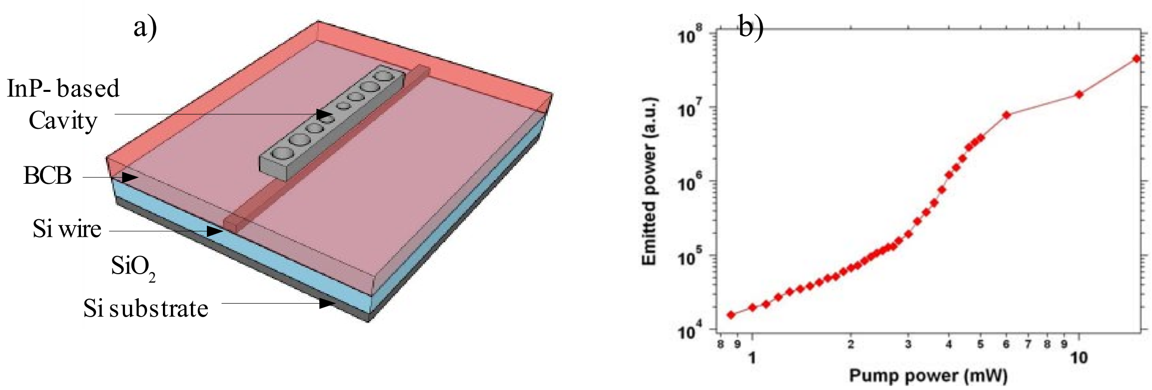

Figure 3, a) Schematic of the wire cavity bonded on SOI waveguide. b) Light-Light curve for the wire cavity laser out of the SOI wire

3. Wire cavity laser integrated on SOI waveguides

We then study laser emission from samples bonded to SOI waveguides. The sample is depicted in Fig. 3a, the lower level is composed of narrow Si waveguides (~500nm wide and ~220nm high) where the light propagates passively, and the top layer is the active InP wire cavity PhC laser. Silicon waveguides are fabricated in a CMOS fab using 193nm DUV lithography on SOI, InP wafers are grown by MOCVD. Details on the fabrication may be found in [3]. The emission was detected simultaneously, from the surface of the PhC and at the output of the SOI wire. The results of the measurements are shown Fig. 3b. The variation of the emitted power with the pump power is an S-shaped curve. This shape shows that laser threshold is reached for a peak pump power around 4mW.

4. Conclusion

In conclusion, we demonstrate laser operation with fairly low thresholds. The reduction in size of these lasers points the way to the achievement of densely integrated optical sources for optical interconnection systems. These nanolasers were integrated heterogeneously with SOI waveguides. The direct coupling of laser emission into silicon waveguide was demonstrated. This is indeed a groundbreaking step towards the “siliconization” of integrated optics as it opens the way to efficient intrachip E/O conversion.

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